WETTING PATTERNS FOR LINE-SOURCE TRICKLE EMITTERS

by

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SUMMARY: Wetting patterns in a layered soil were deter-
mined for three trickle tubing placements and two
irrigation application modes. Wetting patterns for the
subsurface tubing placement were not always different
from those for the surface placement, and variation in
soil properties often produced effects similar to those
of different tubing placements.

KEYWORDS: Micro-irrigation, matric potential, soil water
tensiometer, layered soils.

INTRODUCTION

Soil wetting patterns from irrigation are determined by soil properties, the method and rate of water application, and crop water requirements and growth patterns. Wetting patterns for specific line sources and individual emitters are needed in order to properly design micro irrigation systems. This information is particularly important for wide line-source spacings, such as the alternate middle placement being utilized in micro irrigation systems for row crops. In coarse-textured soils, such as those found in much of the southeastern Coastal Plains, the low water storage and water movement require closer line-source spacings than in medium-to-fine-textured soils. Otherwise, irrigation water may not be available to young, developing root systems early in the crop growing season.

Several mathematical models to describe wetting patterns for various micro irrigation emitters have been proposed (Brandt et al., 1971; Warrick, 1986) and have provided reliable results for certain conditions (Bresler et al., 1971; Bresler, 1978). Other models have been developed to describe wetting patterns for emitters operated on the soil surface and buried at various depths within the soil profile (Warrick, 1986). Basic assumptions in the development of most models include a stable, isotropic, and homogenous soil with known hydraulic properties. Unfortunately, most soils do not satisfy these assumptions. The deviation from these assumptions is particularly serious in the southeastern Coastal Plain, where many soils have layers of different texture with significantly different strength, bulk density, and hydraulic properties. The objectives of this study were to determine the wetting patterns in a layered soil for a micro irrigation line source installed in three different locations and operated in both continuous and pulsed modes.

METHODS AND MATERIALS

Measurements were made during a three-year period (1985-87) on a 0.20-ha site of Norfolk loamy sand near Florence, South Carolina. The E soil horizon was poorly defined and appeared to be partially mixed with the lower portion of the Ap horizon which extended to a depth of 0.3 m (Fig. 1). The partial mixing of these layers was probably caused by antecedent deep tillage. Each of the 24 experimental plots had eight 12-m twin rows spaced 0.76 m apart on center. Six treatments were completely randomized in each of four blocks; treatments consisted of all combinations of three micro irrigation tubing locations and two irrigation application modes. Irrigation tubing locations were (1) buried 0.3 m directly under the twin rows, (2) placed on the surface between the twin rows, and (3) placed on the surface in alternate row middles (Fig. 2).

Irrigation was applied through each system in both continuous and pulsed modes. In the continuous mode, irrigation was applied without interruption until the desired amount was applied. In the pulsed mode, irrigation was applied in a series of pulses such that on and off times were equal and the duration of each was either 20 or 40 min depending upon the number of laterals.

Subsurface trickle tubing was installed 0.3 m deep using a modified subsoiler shank in the fall of 1984 and remained in the soil continuously. At this depth, the trickle tubing was near the interface between the Ap and B horizons and below the frost line (Fig. 1). Tubing for surface placement was installed each season after a stand was established and was removed prior to harvest. Each irrigation lateral was equipped with a removable end cap that was utilized for line flushing. The micro irrigation tubing (Lake Drip-In*) had in-line, labyrinth-type emitters spaced 0.61 m apart, each delivering 1.9 L/hr. Treatments in which laterals were placed on or under each twin row required 8 laterals per plot, while the alternate middle treatment required four laterals. All laterals within a plot were connected to a single manifold where flow was controlled by a solenoid valve and pressure was regulated at approximately 100 kPa by individual pressure regulators in each manifold.

Prior to installation of the micro irrigation system, the site was subsoiled in two different directions (45° to row direction and perpendicular to each other) and was disked until the surface was smooth. After installation of the subsurface micro irrigation tubing, the only tillage used was disking and smoothing to remove weeds and to incorporate preplant broadcast chemicals. All sidedressed N and S was injected through the irrigation system. The irrigation water supply was filtered using a 100-mesh cartridge filter. At the beginning of each growing system and periodically during the season, all end caps were removed, and the system was flushed to remove any sediment or residue that might cause emitter plugging. At the end of the growing season, a concentrated chlorine solution was injected into the system to reduce biological activity and to retard entry of roots into the emitters during the dormant season.

Rainfall was measured on site with a tipping-bucket rain gauge connected to an automated weather station. Tensiometers were installed at depths of 0.30, 0.60, 0.90, and 1.20 m at two locations relative to the emitter (at the emitter and midway between emitters) and at the lateral line and at two distances perpendicular to the irrigation lateral. These distances were 0.19 m and 0.38 m for the two in-row tubing placements and 0.38 m and 0.76 m for the alternate middle placement. This provided a total of 24 tensiometers in each of six plots, one plot for each treatment (Fig. 3). Tensiometer readings were recorded three times each week, and tensiometers were serviced at least once each week during the growing season.

Although 24 tensiometers were located in each plot, they did not provide replication because each was located in a different position relative to the emitter, and they were located in only one plot of each treatment. The high-frequency irrigation application mode did not allow significant soil drying between applications. The combination of high irrigation frequency and the lower tensiometer reading frequency made it impossible to evaluate short-term changes in soil wetting patterns. Consequently, detailed wetting patterns were determined following harvest in 1987 by gravimetric sampling. This was done for surface, in-row and buried, in-row treatments. Soil water content was determined along two lines, one perpendicular to the

line source emitter and one parallel to the line source, each
originating at the emitter (Fig. 4). The soil profile was initially
sampled following a significant period without either rainfall or
irrigation. Irrigation (12 mm) was then applied in a continuous mode,
and the soil profile was sampled at 1-, 24-, 48-, and 144-h intervals
following irrigation. Soil water contents following irrigation were
normalized relative to the initial soil water content and plotted
using the G3GRID interpolation program and GCONTOUR plotting program
(SAS, 1985). Contours were prepared for an area including both sides
of the emitter by assuming symmetry about the emitter.

RESULTS AND DISCUSSION

Total growing season rainfall and irrigation amounts for all
treatments and for all three years are included in Table 1. Rainfall
and irrigation distribution during the growing season in 1985, 1986,
and 1987 are shown for all treatments in Fig. 5. Rainfall was highest
in 1985 (288 mm), lowest in 1986 (174 mm), and intermediate in 1987
(213 mm). One of the worst droughts of this century occurred during
the corn-growing season in 1986 and was particularly severe during the
early part of the growing season. Consequently, irrigation amounts
for all treatments were highest this year, but they were also
moderately high in 1987.

Matric potential values, as measured by tensiometers, at four
soil depths for the corn-growing season in each of the three years are
shown in Fig. 5. While these values were measured in only one
treatment, those measured in other treatments were similar. Matric
potential was generally maintained below 30 kPa throughout the entire
growing season and, in most cases, was maintained below 25 kPa. Each
matric potential value in these figures represent the mean of all
locations relative to the emitter. These results indicate that the
irrigation management criteria of maintaining the matric potential at
the 0.3-m depth below 25 kPa was generally successful. However, this
was not true in all treatments, as can be seen in Fig. 6, which shows
matric potential at four depths, rainfall and irrigation for three
tubing placements, and two application modes throughout the 1985
growing season. It is evident that all matric potentials were not
maintained within the target zone of 25 kPa. This was particularly
true for the surface tubing placements. Although these matric
potential values represent the mean of all locations relative to the
emitter, values are not replicated for each treatment in another
location. Consequently, it is not possible to remove the effect of
spatial variability from treatment effects.

Matric potential contours for all three tubing placements and
application modes are shown in Fig. 7 for day 165 in 1985. These
values reflect soil conditions one day after irrigation of an
initially dry soil. For the surface in-row placement, the wetting
pattern was narrower for the continuous mode than for the pulsed mode.
However, the depth of wetting was greater for the continuous mode than
for the pulsed mode. In the alternate-middle placement, soil in the
continuous mode treatment appeared to be much drier than that in the
pulsed-mode treatment. The apparent dry condition for the alternate

middle continuous treatment could have been caused by local soil conditions which affected infiltration and/or movement within the profile. Matric potential values were generally lower for the subsurface tubing placement, and there was a little difference between the continuous and pulsed application modes for that placement.

Soil water content values normalized with respect to the preirrigation values are shown in Fig. 8 for a subsurface tubing location at 1, 24, 48, and 144 h following irrigation. With the tubing located at a depth of 0.30 m, one would expect the higher water content to be near that location. However, this was not the case as higher water contents were measured near the soil surface, similar to that expected for the surface tubing placement. Each soil water content value shown here is the mean of four replications for the subsurface tubing location. The wetted zone was limited to a volume extending a distance of 150 mm horizontally from the emitter in all directions and upward from the tubing depth (300 mm) to the surface. There was no evidence of downward water movement from the emitter. This might have been caused by restrictive properties of the compacted E horizon which was immediately below the tubing. However, there was no evidence of unusually great horizontal water movement in the vicinity of the emitter as might be expected if downward flow were restricted. These results support observations of upward water movement, essentially in a column immediately above the emitter. It is possible that this movement occurs through a zone of residual disturbance resulting from the original installation. At 144 h following irrigation, the soil water content had essentially returned to the initial soil water condition, although there was a small, slightly wetter zone at the 0.35-m depth.

Soil water content contours normalized to preirrigation values for the surface tubing placement at 1, 224, 48, and 144 h following irrigation are shown in Fig. 9. At 1 h, the wetting front had reached the 0.45-m depth, and the surface had been wet to a radius of about 250 mm from the emitter. This pattern is what one would expect with a surface irrigation source. At 24 h, the wetted zone had started to decrease, extending to a depth of only 0.4 m. This trend continued at the 48-h measurement, and the soil profile had essentially returned to the preirrigation level at 144 h.

To determine the variation in wetting patterns among the four replications, soil water content contours were prepared for each replication in both the surface and subsurface placements. Contours for four replications of the surface placement at 24 h following irrigation are shown in Fig. 10. While each of the replications reflect different contour patterns, three of them show a more vertical wetting front. There are notable differences even among these three patterns. Consequently, we concluded that significant differences in infiltration and water movement exist within the profile among the four locations. Similar soil water content contours for the subsurface tubing placement at 24 h are shown in Fig. 11. Similarly, one can see that three of the replications had a more horizontal wetting pattern while the fourth had a distinctly vertical wetting pattern. Again, within the three predominantly horizontal wetting patterns, there are significant differences among the three locations.

From the information shown in these soil water content profiles, it is evident that soil conditions greatly affect the wetting patterns, both from the standpoint of infiltration, in the case of surface placement, and internal water movement in both tubing placements. In some cases, it appears that there may be as much difference in the wetting pattern among replications with the same tubing placement as there is between the two tubing placements.

Results from the analysis using analysis of variance procedures and considering each day as a replication did not indicate any significant effects. Analyses of this type will be continued in an effort to determine differences among tubing placements and application modes for these soils.

CONCLUSIONS

Three trickle tubing placements and two application modes provided similar soil water regimes during the 3-year period of the study (1985-87) although there were differences in wetting patterns among treatments. Treatments in which tubing was placed on the soil surface generally required more water and matric potential values were generally higher. In many cases, the wetting pattern for the subsurface tubing placement was similar to the pattern for the surface in-row placement.

In an intensive measurement period following harvest in 1987, soil water content returned to pre-irrigation levels within six days following irrigation. Wetting patterns again were not consistently different between the surface and subsurface tubing placements. Variation in wetting pattern among the four measurement locations (replications) were often as great as that between tubing placements. Variation in soil hydraulic properties were probably responsible for this variation.

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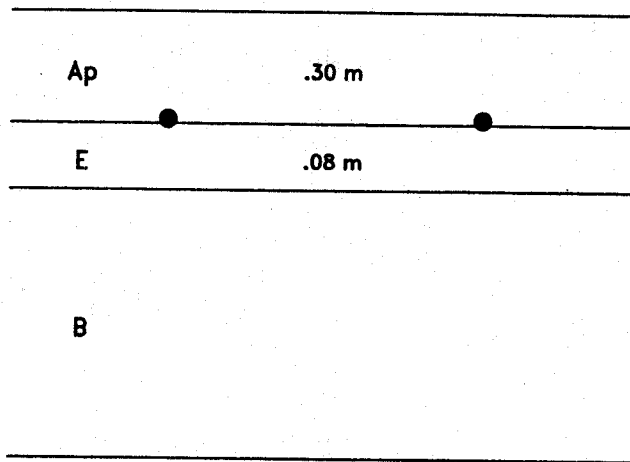
Soil Profile

Ap   .30 m

E   .08 m

B

Fig. 1. Profile of layered Norfolk loamy sand in southeastern
         Coastal Plain

(a) Subsurface, In-Row

← .76 m →

(b) Surface, In-Row

.76 m

(c) Surface, Alternate middle

1.52 m
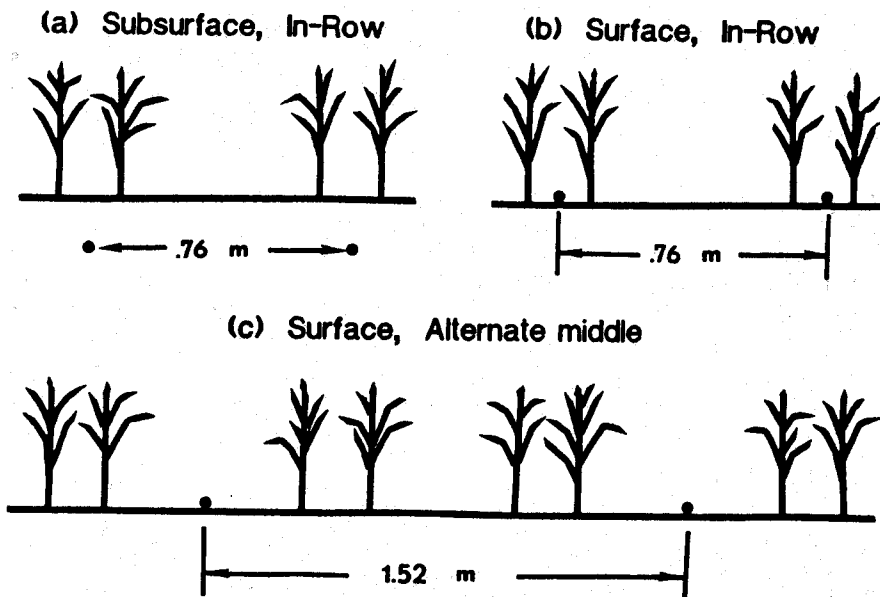
Fig. 2. Schematic diagram of micro irrigation tubing placements

Tensiometer Placement

(a)   Subsurface & Surface

| 305 mm | 305 mm | Row

190 mm

190 mm

Row

Emitter

(b)   Alternate—middle

Row

| 305 mm | 305 mm | Tube

381 mm   Row

381 mm

Row
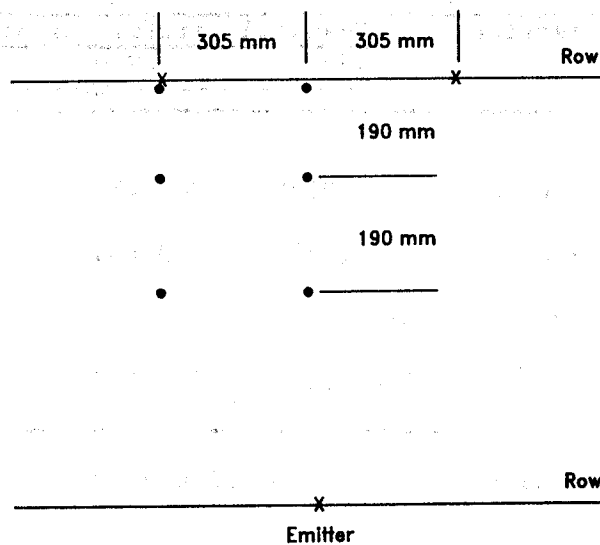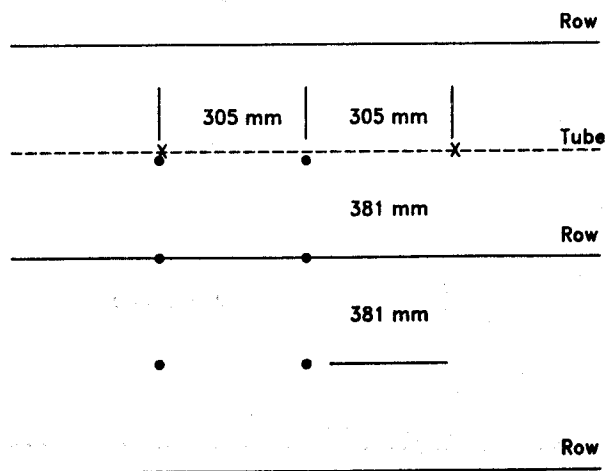
Fig. 3.   Schematic diagrams of tensiometer placements in
          (a) surface and subsurface in-row tubing placements,
          and (b) alternate-middle tubing placements

Table 1. Seasonal rainfall or irrigation amounts for three trickle irrigation systems in a Coastal Plain soil.

Trickle irrigation treatment	Seasonal rainfall or irrigation		
	1985	1986	1987
	----------------mm----------------		
Subsurface, in-row	279 (36)*	362 (53)	337 (51)
Surface, in-row	318 (38)	413 (55)	337 (51)
Surface, alternate	318 (38)	375 (55)	362 (55)
Rainfall	288 (36)	174 (28)	213 (27)

* Number of irrigation or rainfall events.

Gravimetric Sampling Sites

X - Emitter

76 mm

305 mm   305 mm   Tube
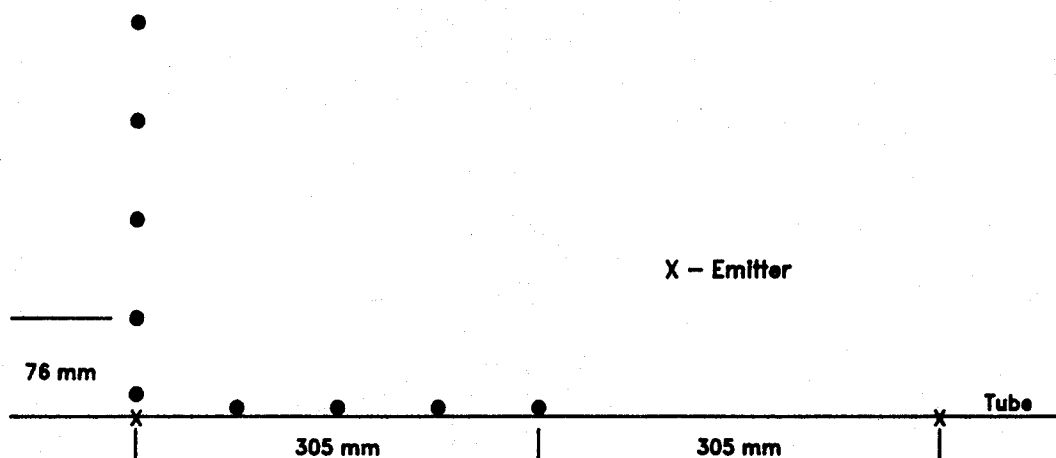
Fig. 4. Schematic diagram of soil sampling sites for gravimetric determination of soil water content in post-harvest wetting pattern evaluation.
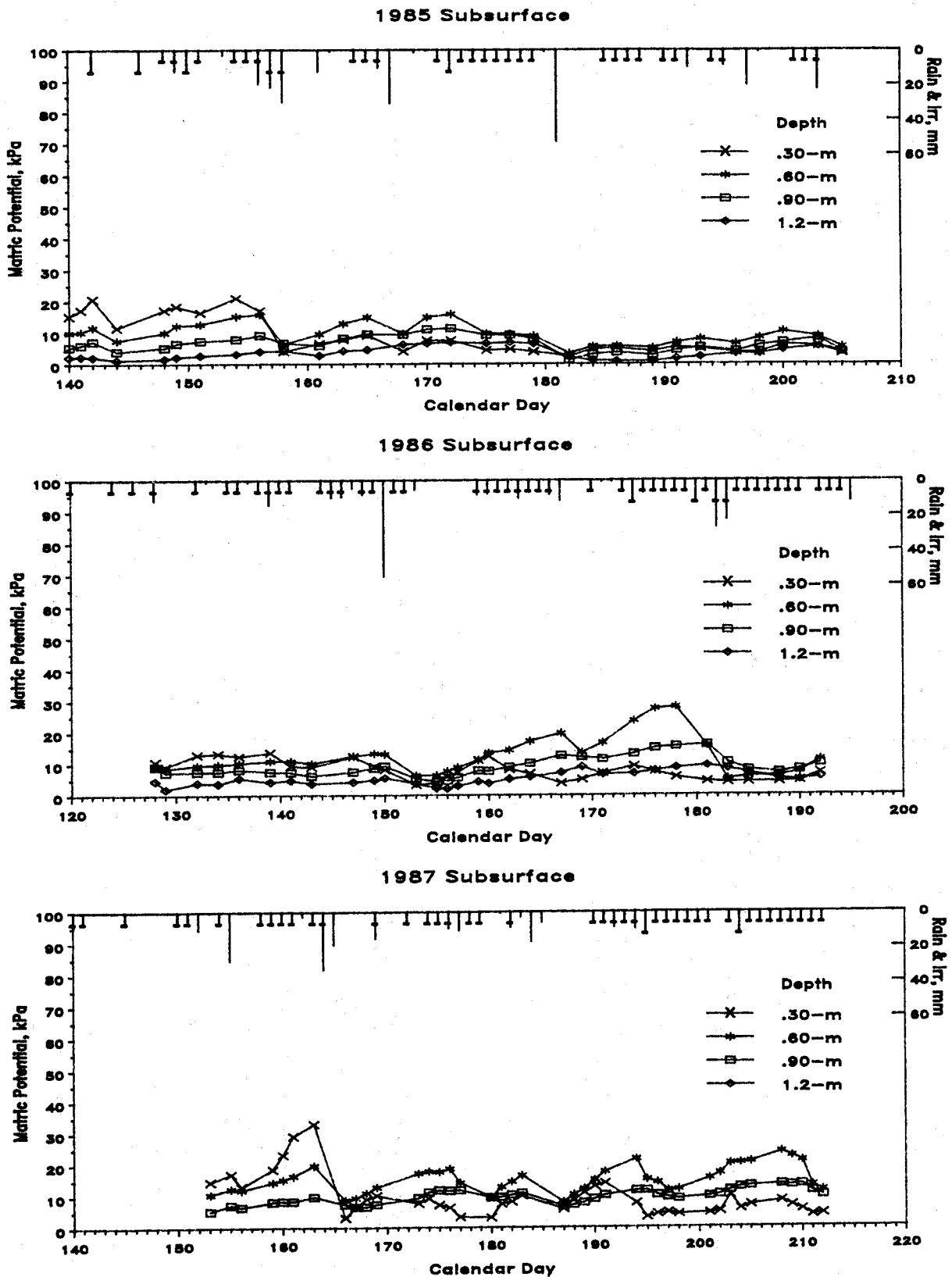
Fig. 5. Growing season rainfall, irrigation, and matric potential values during 1985, 1986, and 1987 for the subsurface placement, continuous mode. Each matric potential value is the mean of all locations relative to the emitter at a given depth. Rainfall is shown as a line (without bar) and is added to the irrigation value when both occurred on the same day.
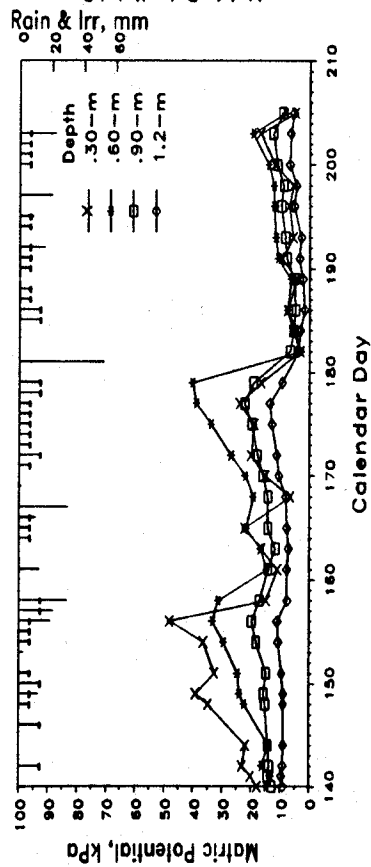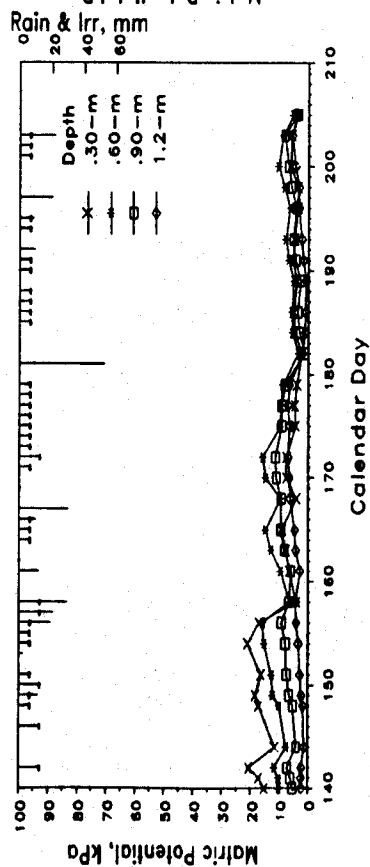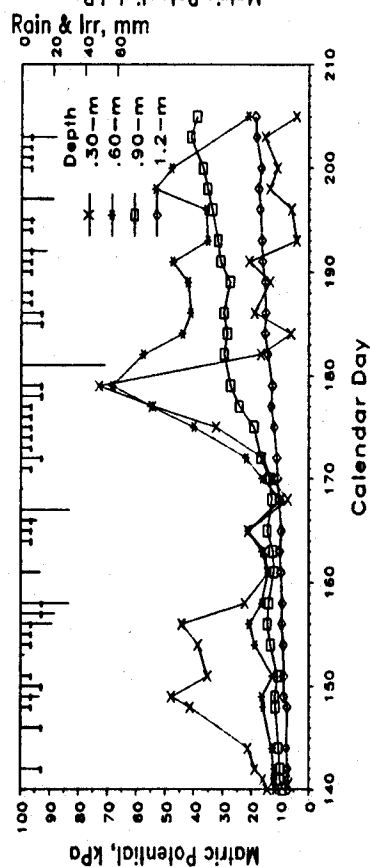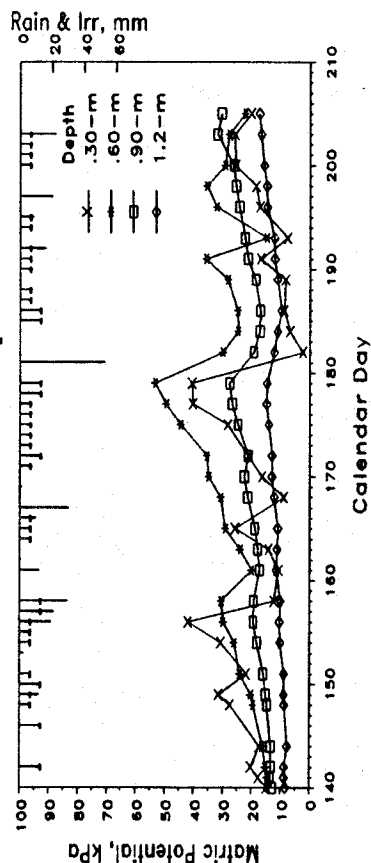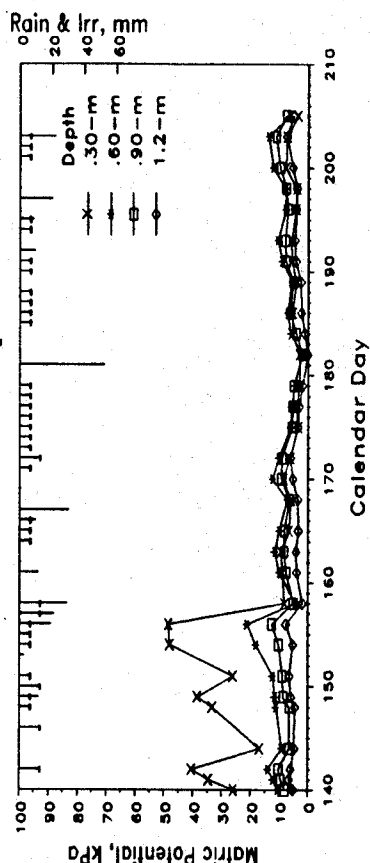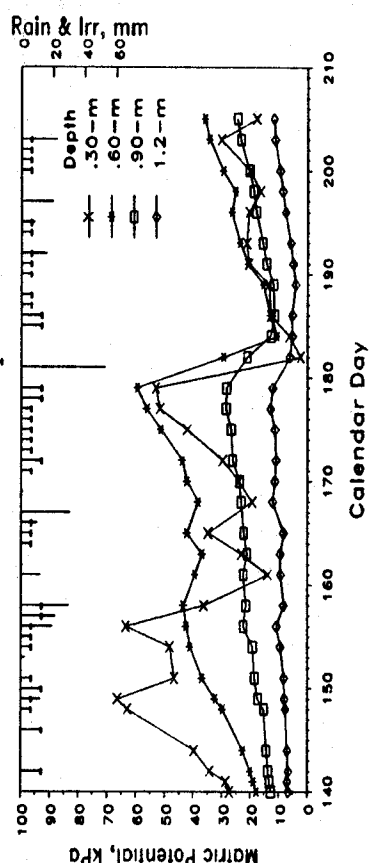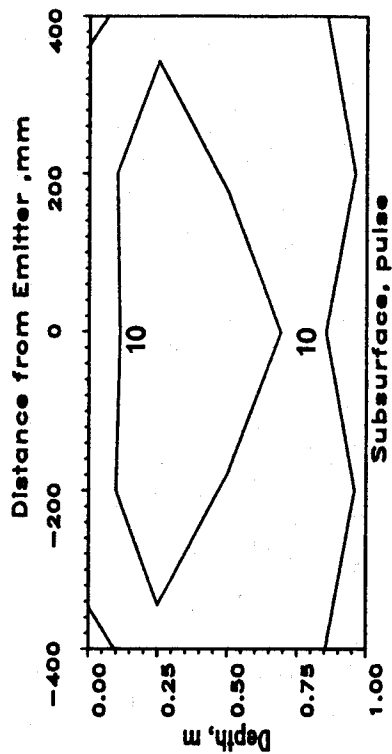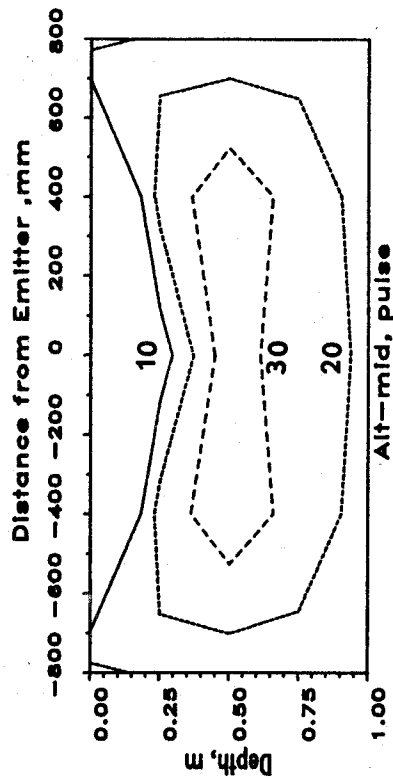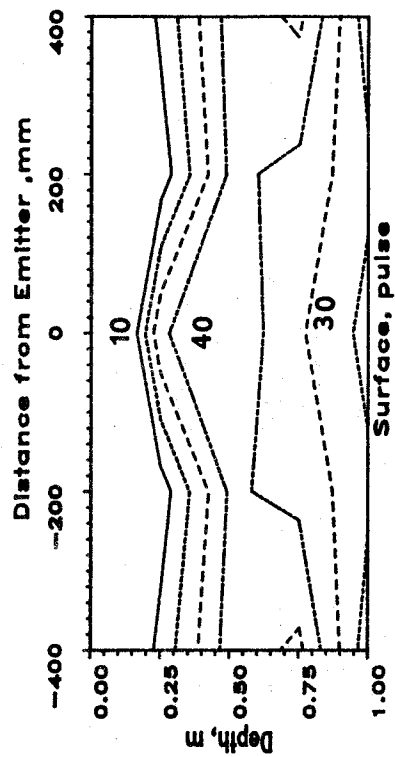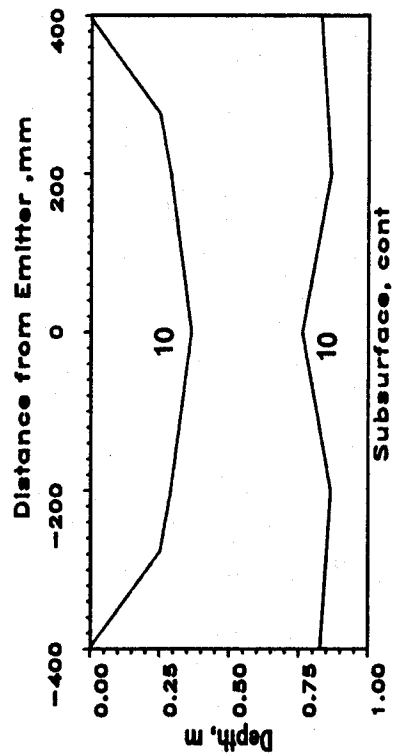
Fig. 6. Growing season rainfall, irrigation, and matric potential values for six tubing placement and application mode treatments in 1985. Each matric potential value is the mean of all locations relative to the emitter at a given depth. Rainfall is shown as a line (without bar) and is added to the irrigation value when both occurred on the same day.
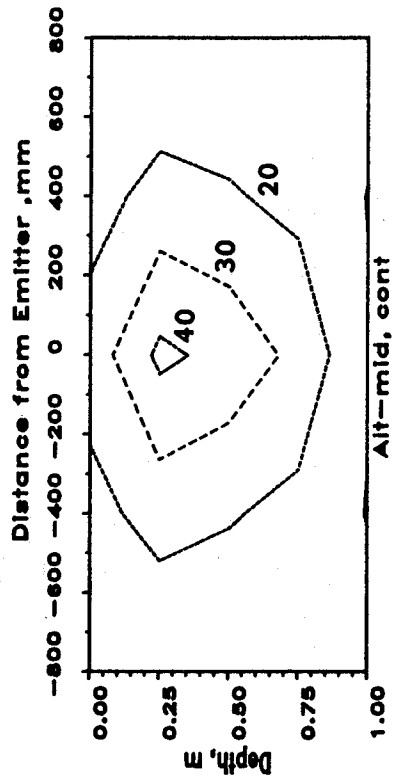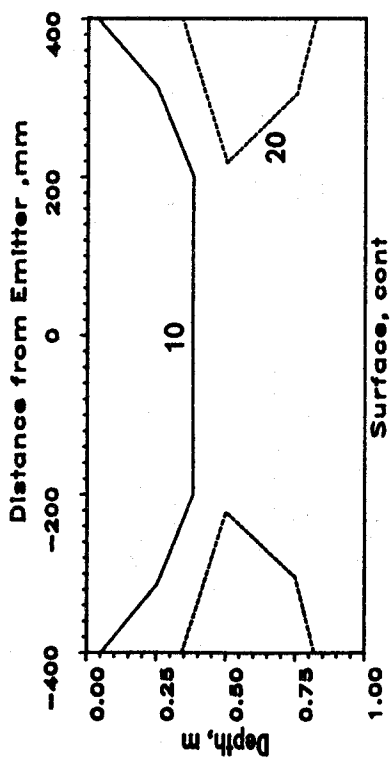
Fig. 7. Matric potential (kPa) contours for six tubing-placement and application-mode treatments using tensiometer data for day 165, 1985.
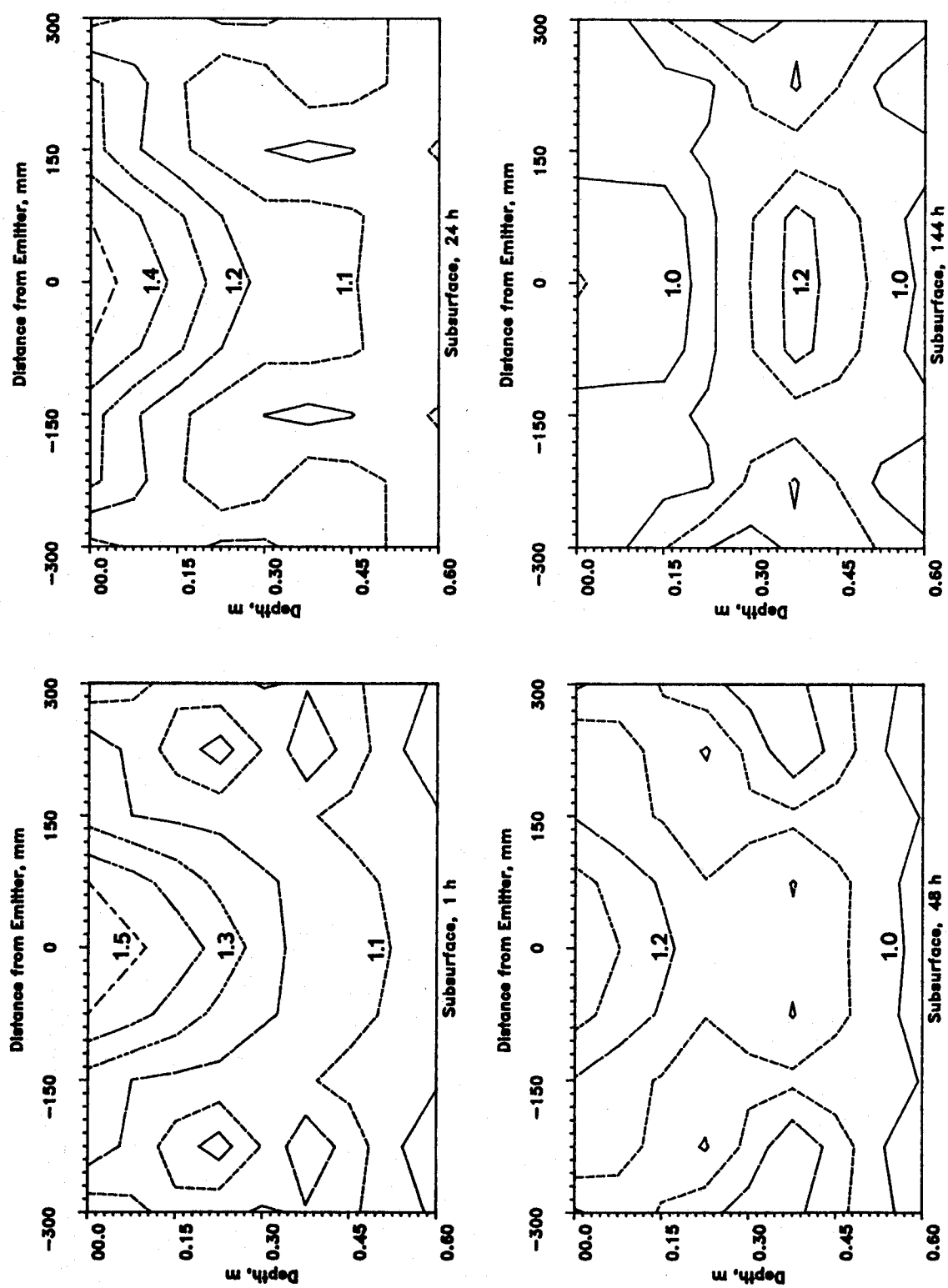
Fig. 8. Normalized soil water content contours for 1, 24, 48, and 144 hours following irrigation in subsurface tubing placement.
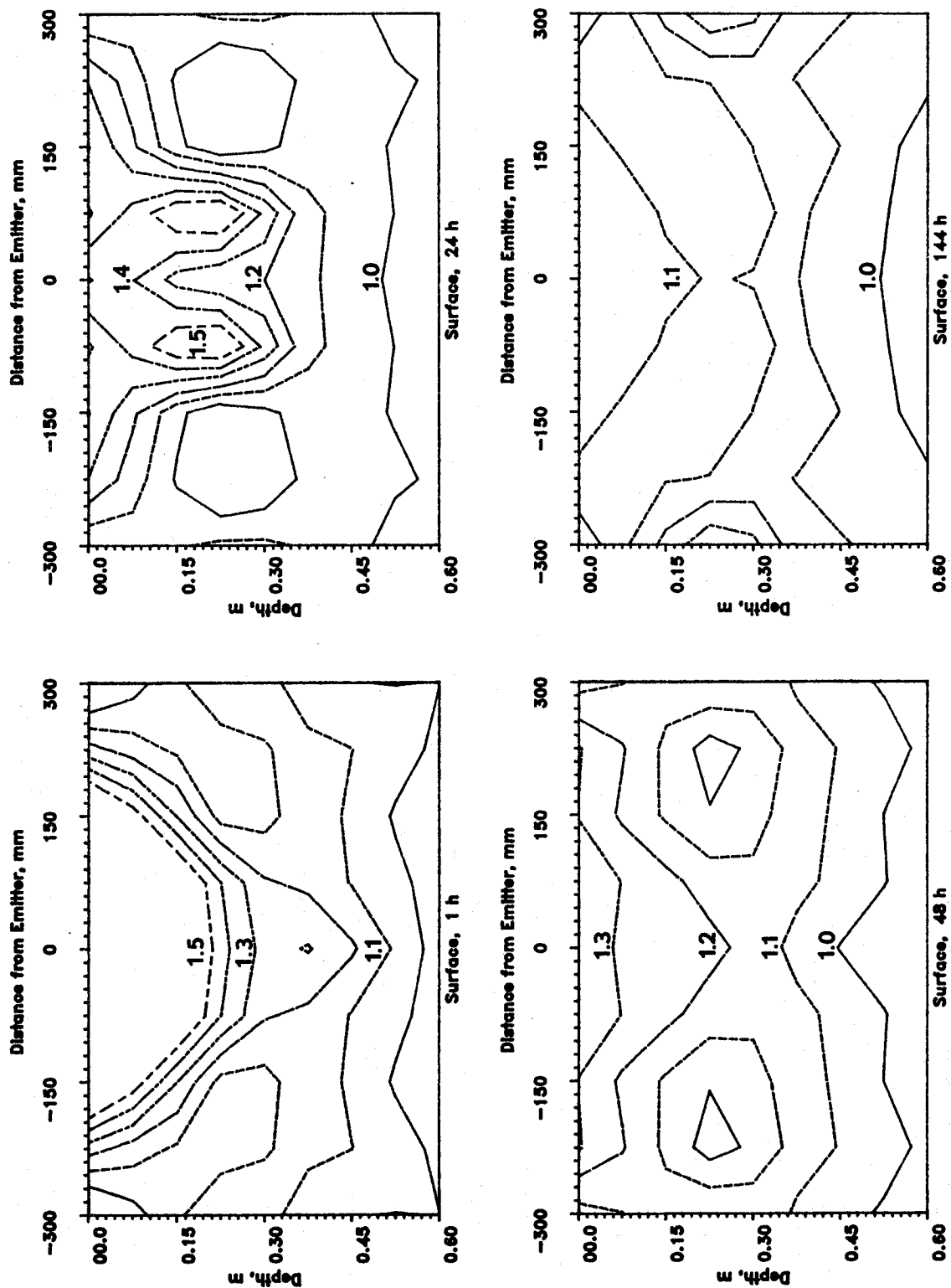
Fig. 9. Normalized soil water content contours for 1, 24, 48, and 144 hours following irrigation in surface tubing placement.
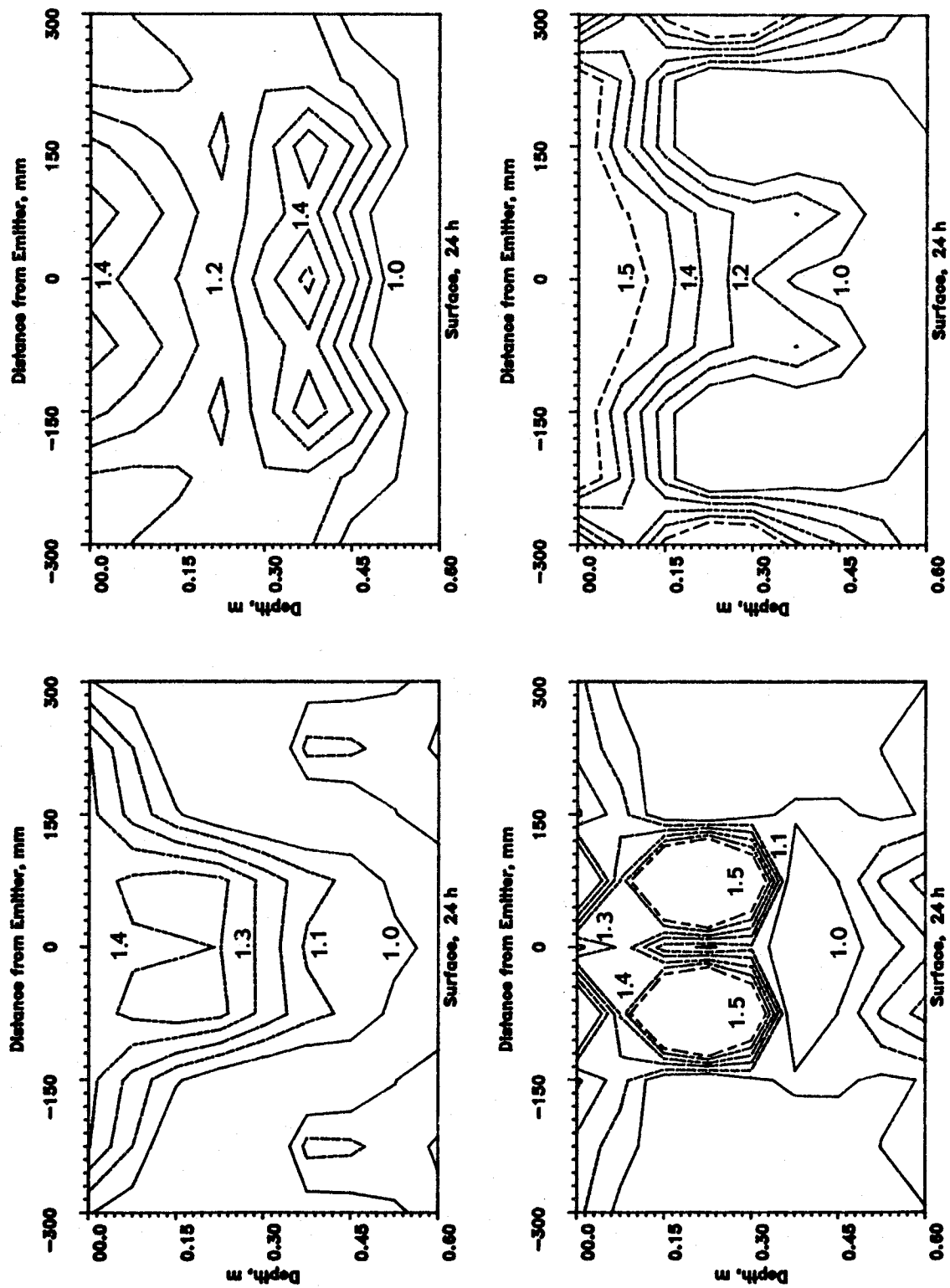
Fig. 10. Normalized soil water content contours for four locations (replications) of surface tubing placement 24 hours following irrigation.
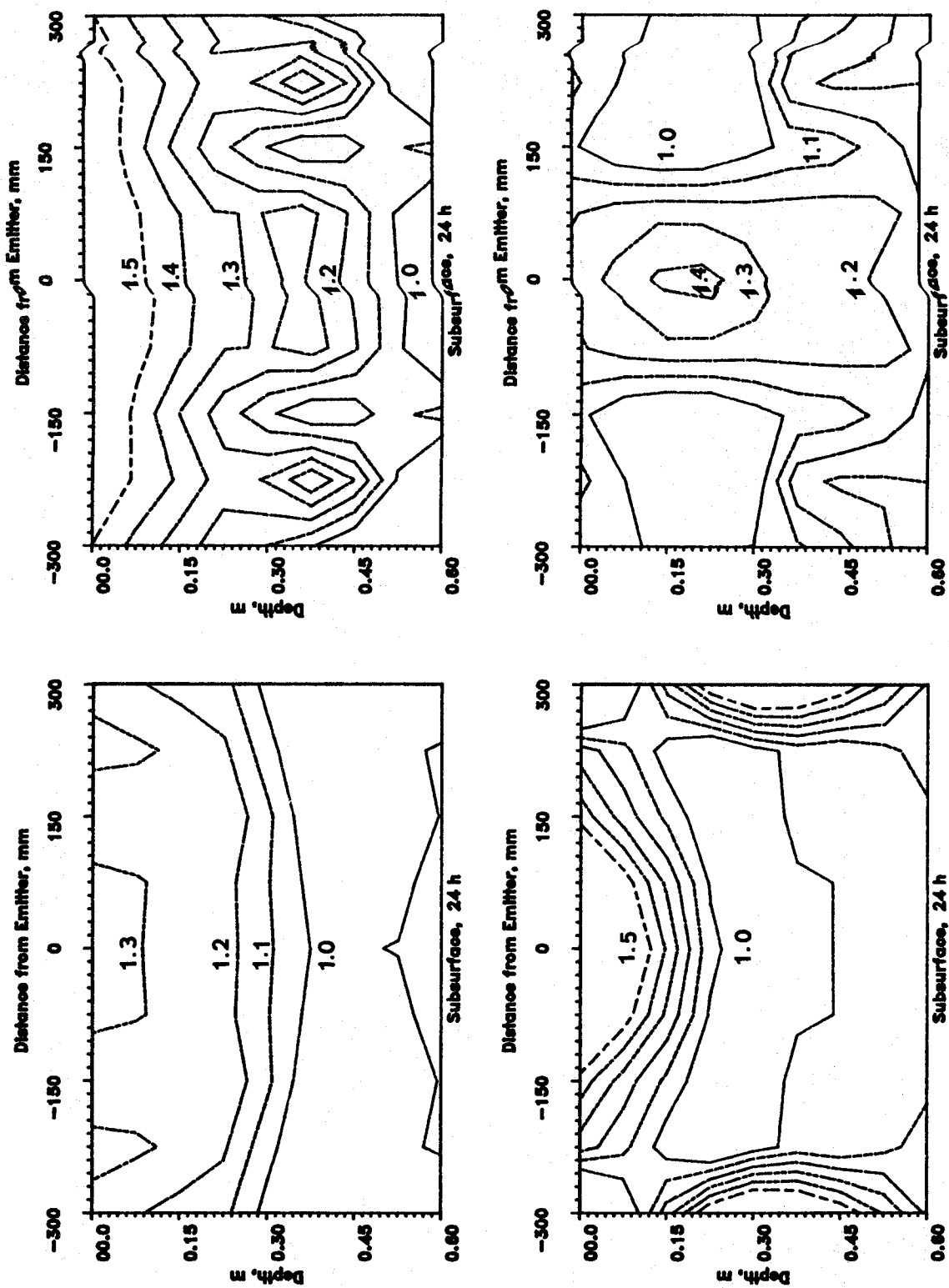
Fig. 11. Normalized soil water content contours for four locations (replications) of subsurface tubing placement 24 hours following irrigation